UNIVERSITY OF ILLINOIS, SYMPOSIUM DECEMBER 1988

BUILDING SYSTEMS: ROOM AIR AND AIR CONTAMINANT DISTRIBUTION

SYMPOSIUM TOPIC: VENTILATION MEASUREMENT AND VENTILATION EFFICIENCY

PAPER TITLE: DETERMINATION OF OUTDOOR AIR QUANTITIES DELIVERED

BY: DAVID W. BEARG, P.E. & WILLIAM A. TURNER, P.E.

ABSTRACT

As part of an indoor air quality investigation protocol, frequently the quantities of outside air being delivered to the occupants of a building is identified as in need of assessment.

Methods frequently utilized for this task include tracer decay assessments and the measurement of indoor CO^2 levels, assumed to be generated by the occupants. This paper presents data from buildings in which both CO^2 measurement and tracer gas decay were performed separately or simultaneously in order to assess the amounts of outside air reaching the occupants.

The methods utilized will be explained and discrepancies in the results of the two methods will be discussed. Discussion of "ventilation efficiency" - (the delivery of outside air to the occupied space vs. the quantity of outside air brought in at the air intake) are presented.

Protocols are suggested which are expected to minimize errors in the correct interpretation of the results and further research needs are discussed.

2025525822

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

INTRODUCTION

As part of an indoor air quality investigation protocol, the major focus is frequently a determination of the quantities of outside air (OA) actually being delivered to the occupants of a building. This quantity of OA being delivered to the occupants is a function of both the quantity of OA taken in at the OA dampers and the effectiveness of the HVAC system in delivering this air to the people. In this paper, it is the ratio of the air quantity entering the OA dampers and the outside air quantity delivered to the occupants that is referred to as the "ventilation efficiency." It is desirable to know this ventilation efficiency in order to determine if improvements in delivery efficiency are warranted. Measurement of both the delivered quantities of outside air and the efficiency of the ventilation system are especially important in light of various protocols for design options that are contained in proposed ASHRAE Standard 62-1981R, "Ventilation for Acceptable Indoor Air Quality." The two principal tools currently utilized for evaluating the quantity of outdoor air delivered to the occupants of a building are the measurement of carbon dioxide (CO^2) concentrations and the measurement of tracer decay rates using sulfur hexafluoride. These methods have also been utilized by the authors and other researchers to assess the efficiency of outside air delivery. Each of these techniques has its own set of advantages and disadvantages, but the performance of the two together tends to cancel out some of the weaknesses. Therefore, whenever possible, the authors have performed both procedures side by side to maximize the precision and the accuracy of the results. This paper discusses some of the issues raised by these comparative results.

2025525823

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

AUTHOR INFORMATION

David W. Bearg is President of Life Energy Associates, Concord, MA.

William A. Turner is Manager of the Building Air Quality Group, Harriman Associates, Auburn, ME.

METHODS

Discussion of Information That Can Be Derived From Carbon Dioxide Testing

The ventilation rate determination using CO^2 measurements compares the indoor concentrations with outdoor concentrations and assumes that the increase in indoor values is due to the buildup of CO^2 expired due to respiration by the building occupants. This relationship is detailed in Appendix D of the ASHRAE Standard 62-1981 (ASHRAE 1981). The advantage of this technique is that relatively few measurements obtained during the peak afternoon occupancy period can provide a determination of the quantity of ventilation air being provided. These results express the ventilation rate in terms of cubic feet per minute of outdoor air per person (cfm of OA per person), which are then directly comparable with the recommended minimum OA quantities published in the ASHRAE Standards 62-1981 and 1981R (ASHRAE 1981, 1986).

Although this comparison is very useful, it is not always sufficient for the scope of many evaluations. Most often, in order to compare the quantity of OA delivered with the quantity entering the HVAC system, the quantities need to be expressed in terms of just cfm of OA. The cfm of OA at the air intake is determined by flow measurements, while the delivered quantity is the product of the CO^2-derived cfm/person value and the total number of people present at the time of the test measurements. In actual testing situations then, it can be important to know exactly how many people are actually present in the space at the time of the CO^2 measurements. For populations up to 30 or so people this

2025525824

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

rarely represents a problem, but for 300 people or so, the ability to count the number of people is much more difficult. Techniques for estimating this population are, of course, possible. As part of building surveys, we have measured not only CO^2 concentrations, but potential number of people per office and actual number of people per office. Then, assuming that the 20% of the "random" offices surveyed are typical of the rest of the building, we can estimate the total building population. This then yields the OA quantity in terms of cfm.

Dividing cfm of OA value by the area involved yields another important evaluation criterion, cfm of OA per square foot. Corporate ventilation standards are often expressed in terms of minimum quantities of cfm of OA/ft^2.

For typical office environments (as defined by the ASHRAE Standard 62-1981R), with 7 people per 1,000 square feet of area, the proposed ASHRAE minimum ventilation rate value of 20 cfm of OA per person is equivalent to 0.14 cfm of OA per square foot of office space. Total air delivery rates, as contrasted from outdoor air delivery rates, are typically around 1.0 to 1.2 cfm per square foot of office space.

In addition to expressing the ventilation rate in terms of cfm of OA per person or per square foot, the ventilation rate can also be expressed as the number of air changes per hour (ach). It is this expression of the ventilation rate that most accurately represents the rate at which air contaminants are diluted and removed from the space. This is also the format for the results from tracer decay ventilation testing. For the typical office, with 20 cfm/person, 7 people per 1,000 ft^2 and total ceiling heights of about 10 feet, the ventilation rate would be 1.0 ach. Factored into this calculation is the empirical result, from tracer gas studies, that the net effective volume can be estimated as 85% of the gross volume of the space. These distinctions in expressing ventilation

2025525825

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

rates become especially important in atypical spaces. For example, in one evaluation of a complaint building with total ceiling heights of 18 feet, utilizing the CO^2 approach, data were collected that yielded a peak average indoor concentration of 713 ppm with 425 ppm outdoor conditions, yielding a ventilation rate of 36.5 cfm of OA per person. For the population estimate of 300 people, this represented 10,950 cfm of OA. Tracer gas testing conducted at the same time yielded a value of 0.65 ach. When this ach was applied to the area of 60,000 ft^2 and an estimated effective volume of 972,000 cubic feet, it yielded 10,530 cfm of OA. Both of these values can be expressed as 0.18 cfm of OA/ft^2. The question remains, however, as to which criterion is the one to use in recommending a ventilation rate sufficient to prevent complaints of inadequate ventilation. In this situation, it is the ventilation rate expressed in terms of ach that is most directly concerned with the rate at which air contaminants such as environmental tobacco smoke (ETS) is diluted and removed from this space.

Research Need:

The determination of the most appropriate ventilation goal and the criteria of meeting that goal; i.e., cfm/PERSON, cfm/ft^2, or ach can have a profound effect on the resulting air quality in the space and the amount of outside air needed to provide acceptable air quality. It is in this area where more research is required, especially related to the efficiency of delivery of the outside are to the breathing zone, or occupied zone.

Measurements of CO^2 concentrations at different indoor locations can point out localized variations in ventilation rates throughout the building.

Measurements comparing the concentrations in the supply ductwork and the return ductwork as well as the occupied spaces can characterize the ratio of

2025525826

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

outdoor air to recirculated air leaving the HVAC equipment. Measurements obtained in the early morning can document the persistence of air contaminants from the evening before where the building occupancy extends beyond the operation of the ventilation system. Early morning measurements can also document the impact of air contaminants from parking garages.

LIMITATIONS OF CARBON DIOXIDE TESTING ALONE

The measurement of CO^2 concentrations has also been used by the authors to detect the presence of inadequately vented combustion appliances; e.g., a poorly vented gas-fired hot water heater in a university building. The interference of CO^2 from sources other than the unaccounted for presence of the products of combustion can lead to very erroneous ventilation rates. This was reported in the case of an investigation of a warehouse/showroom that was heated with direct-fired gas heaters. Therefore, in order to trust the results from a CO^2 analysis, it is necessary to be certain that there are no products of combustion entering the building or mechanical systems.

Another disadvantage of this approach is the requirement for a sufficient density of people in order to obtain a measurable increase in indoor concentrations as compared with out-door concentrations. The extreme example of this is when we have been called upon to evaluate a building that has been evacuated and is devoid of the products of human respiration. This situation then requires the use of tracer testing for a ventilation rate evaluation.

2025525827

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

METHOD

Discussion of Information That Can Be Derived From Tracer Gas Testing

As already mentioned, the tracer decay testing approach yields its results in terms of ach. This approach is based on measuring the rate of decrease of a tracer, such as sulfur hexafluoride, that has been uniformly dispersed throughout the space under investigation. If the space under investigation is behaving as a single, well-mixed chamber, the measurements will yield a straight line on semilog plot. The slope of this plotted line is equivalent to the ventilation rate and can be expressed in terms of ach. Calculations are based on the relative changes in tracer concentration and do not require an absolute calibration of the analytical equipment.

Many office spaces, with typically in excess of 85% of the air being recirculated, result in at least the supply air being well mixed. Distribution inefficiencies, however, may result in stagnant zones in the occupied spaces which are not well mixed. Distribution inefficiencies, such as a well mixed zone near the ceiling and stagnant areas below will also complicate the analysis by causing a deviation from the single zone assumption.

The actual shape of the tracer decay plot provides useful information to characterize the behavior of the ventilation system. Slopes that deviate from linearity (on a semilog plot) indicate variations from the well-mixed case; slopes with the appearance of an increasing slope with time are representative of displacement or plug flow, while slopes with the appearance of a decreasing slope with time are representative of incomplete mixing and zones of stagnation. As with the CO^2 approach, the quantity of OA may need to be expressed in terms of just cfm of OA in order to evaluate the performance of the HVAC system. This value can be determined by multiplying the tracer decay

2025525828

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

derived ventilation rate, in ach, by the volume into which the tracer was dispersed. This mixing volume for the tracer is referred to as the "effective volume" and can be determined from procedures that require a very precise determination of the rate of tracer release and the absolute quantity of the tracer measured.

Research Need

Most building investigations do not have the budgets to support the precise determination of the effective volume of the tracer dilution, thus an estimate based on the gross volume is more typically used. Our experience indicates that estimates of effective volume that are 85% of the gross volume yield reasonable results. This is an area where more research is required.

COMPARATIVE ADVANTAGES AND DISADVANTAGES OF EACH APPROACH

The authors have been known to say that "most buildings are similar but each building is unique." It is some of these unique situations that point out the strengths and weaknesses of these two investigatory approaches. In one example, one part of a building was being impacted by air contaminants being generated in another part of the building. The air flow relationship was such that the air being delivered to the space being evaluated had already traveled through another occupied part of the building. Tracer decay testing alone performed in this space would fail to take this into consideration and yield an outside air ventilation rate much higher than is actually being provided. The CO^2 approach, however, by measuring the concentration in both the supply air and occupied space would provide a more accurate assessment of the outside air ventilation rate (in an occupied building). In this situation, the evaluation included several locations in a building complex that consisted of two adjacent buildings that had been interconnected. The direct release of the tracer into

2025525829

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

the occupied area of the smaller of the two original buildings, with 4,100 ft^2 per floor (the adjoining building has 16,500 ft^2 per floor), yielded a linear decay rate equivalent to 4.3 air changes per hour. For the estimated volume of this space, this represented 2,320 cfm of OA. The CO^2 test results, however, based on 700 ppm indoors and 400 ppm outdoors with 17 people present in the space yielded a ventilation rate of 35 cfm per person or a total of 595 cfm of OA. An additional tracer test of the same study area, but with the tracer being released into the HVAC system located in the larger building three floors above, yielded a tracer decay rate equivalent to 1.1 ach. This 4,100 ft^2 area had a total ceiling height of 9.3 ft leading to a gross volume of 38,100 ft^3. Using the previously mentioned relationship of the effective volume for occupied office spaces being 85% of the gross volume, the net volume is 32,400 ft^3 and the 1.1 ach yields an effective ventilation rate of 594 cfm of OA, which is the same result as that from the CO^2 calculation.

This example also points out that with both assessment approaches, it is crucial to be familiar with the design of the HVAC system as well as its intended modes of operation and the need to be aware of any changes in the operation of the system that could affect the quantity of OA being delivered throughout the testing period.

Since it is easier to perform the CO^2 measurements than to perform the tracer analysis, the CO^2 technique will be the more likely analytical procedure of choice. Specific reasons for performing both procedures are situations where there are only low densities of people in the space of concern, or it is difficult to assess the number of people present in the building, or if it is important to understand the air movement patterns among adjacent zones of the building.

2025525830

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000

REFERENCES

ASHRAE. 1981. ASHRAE Standard 62-1981, "Ventilation for acceptable indoor air quality." Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASHRAE. 1986. ASHRAE Standard 62-1981R, "Ventilation for acceptable indoor air quality." Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

ACKNOWLEDGEMENTS

The authors wish to thank all of our clients who have so willingly cooperated in our building investigations and allowed our findings to be utilized for educational purposes. We would also like to thank the support staff of Harriman Associates for the preparation of this manuscript.

2025525831

Source: https://www.industrydocuments.ucsf.edu/docs/pnmm0000